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Seamless Handover in Mobile IP-based Next Generation Networks

- A Cross-Layer Solution for Ubiquitous Communication over Optimized Routes in IPv6 Networks -

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Abstract

In order to provide seamless handover services with minimum handover latency and packet loss, IETF has proposed *Fast Mobile IPv6 (FMIPv6)* mobility management protocol which enhances the performance and operational scope of the standard *Mobile IPv6 (MIPv6)* protocol. However, there are technical obstacles and performance issues that need to be addressed before FMIPv6 can be considered feasible for broad deployment in Next Generation Networks.

In the work described in this thesis, different novel solutions are presented that addresses the many open performance issues identified along the operational spectrum of the FMIPv6 protocol. The main objective and motivation is to enhance the seamless performance of the FMIPv6 handover process. The performance of the proposed solutions is tested and analyzed against the existing solutions by means of simulation experiments and analytical calculations. The accuracy of the simulation model has been validated in detail against an experimental test bed.

With regards to packet losses incurred during the candidate access point discovery process, a prerequisite for the *Candidate Access Router Discovery (CARD)* protocol, two iterative scanning algorithms namely the *Full Channel Iterative Scan (FCIS)* and *Single Channel Iterative Scan (SCIS)* have been developed. It is shown that this approach improves not only the throughput performance significantly but also the accuracy of the handover decision process. In consideration of the experience gained from the FCIS and SCIS investigation and the FMIPv6's reliance on the CARD protocol, a new *Multi-Hop Discovery of Candidate Access Routers (MHD-CAR)* protocol has been designed that reduces the signaling load on the air link; and also the delay due to the advance discovery process of the next access router. MHD-CAR also provides a *distributed cross-layer platform* to enhance inter-layer cooperation between the mobility functions of the network layer and the data link layer in order to improve the operational capabilities of the mobility management process.

Another major contribution of this thesis is the design and analysis of a novel method called *Proactive Bindings for FMIPv6 (PB-FMIPv6)* protocol that optimizes the FMIPv6 protocol by reducing the tunneling load during the time the Mobile Node is negotiating a handover with the new access router. It also decouples the dependence of the FMIPv6 protocol on the speed of the mobile entity and the timing of the protocol initiation.

Also addressed is the fact that future networks will not only consist of single mobile nodes but also mobile IP subnets with multiple stations (e.g., buses, trains etc.). To manage the mobility of such entities, termed as *Mobile Networks*, IETF has proposed *Network Mobility (NEMO)* protocol but it has lacked to specify a Route Optimization mechanism. The performance inefficiencies due to the absence of such a mechanism get compounded for *nested Mobile Network* architectures owing to *pin-ball routing* phenomenon. This issue is addressed by proposing a solution called *NEst Route Optimization for NEMO (NERON)*, which is an efficient and light-weight solution expected to compliment the standard NEMO protocol in the future networks.

As part of the work, an extensive event-driven simulation framework has been developed and portion of it released to the public, which has solicited a very good response from the developers and research community. Besides, the proposed contributions have also been presented at various forums in the form of conference/workshop proceedings and book chapters. Also noteworthy is the fact that the various solution proposals have been put forward to the IETF standardization body as Internet Drafts, such as PB-FMIPv6, NERON and MHD-CAR, where the last two have been introduced in the context of a research project on mobile transmission of confidential data for fire and rescue services. In the future, the solution concepts developed in this thesis will be used for extending IP based communication services to Unmanned Aerial Systems.

Zusammenfassung

Um in zukünftigen, vollständig Internet-basierten Netzen unterbrechungsfreie Handover-Prozesse mit minimaler Verzögerungen und Paketverlusten realisieren zu können, wurde in der IETF (Internet Engineering Task Force) das Fast Mobile IPv6 (FMIPv6) Mobilitätsmanagement-Protokoll vorgeschlagen. Auch wenn sich wesentliche Leistungsparameter mit FMIPv6 gegenüber dem bekannten Mobile IPv6 (MIPv6) Protokoll verbessern lassen, sind verschiedene technische Probleme bisher nicht gelöst und behindern daher die breite Einführung des FMIPv6 in den Netzen der nächsten Generation.

In hier vorgelegte Arbeit werden verschiedene Lösungsansätze vorgestellt, die offene Probleme adressieren und zu einer substantiellen Verbesserung der Leistungsfähigkeit der Handoverprozessen in IP-basierten Netzen führen. Die Leistungsfähigkeit der erarbeiteten Lösungsansätze wurde im Detail mit Hilfe simulativer und analytischer Methoden vergleichend evaluiert. Das Simulationsmodell wurde im Detail mit einem experimentellen Laboraufbau validiert. In Bezug auf die Minimierung der Paketverluste während der Erkundung von unmittelbar benachbarten Stationen konnte mit Hilfe des Vergleichs zweier Mechanismen, dem sog. Full Channel Iterative Scan (FCIS) und Single Channel Iterative Scan (SCIS) eine deutliche Verbesserung gezeigt werden. Diese Untersuchung führten zur Entwicklung eines neuartigen Mechanismus, mit dem Nachbarstationen in der weiteren Umgebung erfasst und damit frühzeitig erkannt werden können. Das sog. MHD-CARD (Multi-Hop Discovery- Candidate Access Router Discovery)-Protokoll reduziert die Belastung der ressourcenbeschränkten Luftschnittstelle und bietet weitere Möglichkeiten der schichtenübergreifenden Optimierung des Systems. Ein weiterer wesentlicher Beitrag dieser Arbeit ist der Entwurf und die Analyse eines neuartigen Verfahrens zur Reduktion der Netzlast während der Vorbereitung eines Handovers. Durch die proaktive Kommunikation mit dem zukünftigen Zugangsknoten unter Nutzung der Infrastruktur kann die Abhängigkeit des FMIPv6-Protokolls von der Geschwindigkeit der mobilen Stationen entkoppelt werden. Ein weiterer untersuchter Aspekt ist, dass in fortgeschrittenen Szenarien nicht nur die Bewegung einer einzelnen Station zu betrachten ist, sondern auch die Bewegung von Subnetzen mit mehreren Stationen (z.B. in einem Bus oder Zug). Das Problem der sog. Mobile Networks wird durch die IETF durch das NEMO (Network Mobility)-Protokoll grundsätzlich adressiert, jedoch ohne eine ausreichende Optimierung der Routenführung im Netz. Diese Problematik verstärkt sich im Falle von mehrfach ineinander verschachtelten mobilen Netzen (sog. Nested Mobile Networks) und führen zum sog. Pin-Ball-Routing Phänomen. Abschließend stellt die Arbeit daher die Ergebnisse hinsichtlich eines neu entworfenen Protokolls zur Optimierung des Routings. Durch die Ergebnisse der Leistungsbewertung kann gezeigt werden, das das NEMO-Protokoll mit Hilfe des NERON (Nest Route Optimization for NEMO) effizient ergänzt werden kann.

Im Rahmen der Arbeiten wurde u.a. eine umfangreiche ereignisgesteuerte Simulationsumgebung entwickelt, von der Teilergebnisse veröffentlicht und in der entsprechenden Entwickler-community eine sehr gute Resonanz gefunden haben. Besonders hervorzuheben ist weiterhin, dass das MHD-CAR wie auch das MHD-CAR als Internet Draft formuliert und in die IETF-Standardisierungsarbeit eingespeist wurden. Die Ergebnisse der grundlegenden Arbeiten konnten in einem Forschungsprojekt zur mobilen Übertragung von vertraulichen Daten für Rettungskräfte im Brand- und Katastrophenschutz eingebracht werden. In der Zukunft werden die entwickelten Mechanismen auch im praktischen Einsatz Verwendung finden und in einem neuen Projekt IP-basierte Kommunikation zur Steuerung von Flugrobotern weiterentwickelt werden.

Contents

Acronyms

AID	Association Identifier
AP	Access Point
AR	Access Router
BA	Binding Acknowledgement
BC	Binding Cache
BRR	Binding Refresh Rate
BU	Binding Update
BUL	Binding Update List
CAP	Candidate Access Point
CAR	Candidate Access Router
CARD	Candidate Access Router Discovery Protocol
CBR	Constant Bit Rate
CGR	Core Gateway Router
CoA	Care of Address
CoT	Care of Test
CoTI	Care of Test Init
DAD	Duplicate Address Detection
DCC	Discovery of CAR Capabilities
EP	Emergency Personnel
EV	Emergency Vehicle
FMIPv6	Fast Mobile IPv6
FCIS	Full Channel Iterative Scan
FN	Foreign Network
GI	Guard Interval
HAck	Handover Acknowledgement
HI	Handover Initiate
HMIPv6	Hierarchical Mobile IPv6
HN	Home Network
HoA	Home Address
HoT	Home Test
HoTI	Home Test Init
IAPP	Inter Access Point Protocol
IETF	Internet Engineering Task Force
LCoA	Local Care-of-Address
LFN	Local Fixed Node
LLoA	Link Local Address

MHD-CAR	Multi-Hop Discovery of Candidate Access Router
MIPv6	Mobile IPv6
MN	Mobile Node
MNet	Mobile Network
MNN	Mobile Network Node
MNP	Mobile Network Prefix
MR	Mobile Router
MTU	Maximum Transmission Unit
NA	Neighbor Advertisement
NAR	New/Next Access Router
NBSP	NEMO Basic Support Protocol
NCoA	New Care of Address
NEMO	Network Mobility
NEP	Nest Entrance Point
NERON	Nest Route Optimization for NEMO
NG	Neighbor Graph
NGO	Nest Gate Option
NGT	Nest Gate Table
NIC	Network Interface Card
nMNet	Nested Mobile Network
nMR	Nested Mobile Router
NS	Neighbor Solicitation
OptiDAD	Optimistic Duplicate Address Detection
OSA	Open System Authentication
PAP	Present Access Point
PAR	Present Access Router
PB-FMIPv6	Proactive Bindings for Fast Mobile IPv6
PCoA	Previous Care of Address
pCoA	Prospective Care of Address
PESQ	Perceptive Evaluation of Speech Quality
PMIPv6	Proxy Mobile IPv6
PT	Prefix Table
QoE	Quality of Experience
QoS	Quality of Service
RA	Router Advertisement
RAT	Reverse Address Translation
RCoA	Regional Care-of-Address
RFC	Request For Comments
RO	Route Optimization
RPB	Receive Power Buffer
RR	Return Routability
RS	Router Solicitation
RSSI	Receive Signal Strength Indicator
RTD	Round Trip Delay
RTT	Round Trip Time
SAP	Service Access Point

SCIS	Single Channel Iterative Scan
STA	Station
TAP	Target Access Point
TAR	Target Access Router
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UNA	Unsolicited Neighbor Advertisement
VMN	Visit Mobile Node
VMR	Visit Mobile Router
WAT	Wireless Access Technology
WG	Working Group
xMMSEv6	Extensible Mobility Management Simulation Engine for IPv6